Allocation of SKUs to Pods Based on Order Frequency, Association and Dimensions of SKUs to Improve Pile-on of Order Picking in RMFS

Work in Progress

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As e-commerce has become more prevalent, researchers seek more efficient methods of managing warehouses and improving picking operations to reduce costs and inefficiencies. A robotic mobile fulfillment system (RMFS) warehouse is a solution for e-commerce sales growth because it fits many SKUs and demands multiple small-quantity orders. By employing Automated Guided Vehicles (AGVs) to transport inventory pods directly to picking stations, RMFS eliminates unnecessary walking time for workers. Storage Assignment Problem (SAP) is an important topic at the tactical level of RMFS decision problems and a crucial strategy to enhance picking efficiency and order response times. This study adopts a two-step approach, implementing SKU-to-pod policies classification, association rule and integrating product dimensions. Through various scenarios, the effectiveness of these policies in optimizing warehouse operations is evaluated, shedding light on potential conflicts between increased pod utilization and enhanced SKU-to-pod assignment for improved throughput. Insights derived from this research provide valuable knowledge for companies navigating the complexities of warehouse management in the e-commerce era.

Keywords: Robotic Mobile Fulfillment System (RMFS), storage assignment problem, SKU to pod assignment policy, pile-on, pod utilization

Introduction

In the realm of e-commerce operations, efficient order picking stands as a critical bottleneck amidst numerous challenges faced by businesses. In the dynamic landscape of online retail, characterized by escalating customer expectations for rapid order fulfillment, the process of order picking assumes paramount importance. This essential activity not only represents a substantial portion of total warehousing costs, accounting for approximately 55% (Tompkins et al, 2014), but also grapples with issues of accuracy, time constraints and escalating expenses. In response to these challenges, the advent of Robotic Mobile Fulfillment Systems (RMFS) has presented itself as a viable solution, gaining more prominence as e-commerce industry surges. RMFS is a cutting-edge warehouse automation system that operates on a parts-to-picker model. Pods are delivered directly to picking and replenishment stations using Autonomous Mobile Robots (AMRs), streamlining the workflow and minimizing manual labor.

Within the operational framework of RMFS, decision-making processes are delineated into three key domains: order assignment, product assignment & replenishment, and robot task allocation & routing. While much attention is typically directed towards order assignment, the aspect of product assignment & replenishment often remains less discussed, despite its substantial contribution to warehouse efficiency and throughput. The unique challenge presented by the product assignment & replenishment problem within RMFS lies in its nuanced approach. Unlike traditional replenishment paradigms that solely focus on ensuring product availability, RMFS necessitates a more intricate consideration – the assignment of products, or SKUs, to the optimal pods. This optimization extends beyond mere quantity considerations; it encompasses the strategic placement of SKUs within pods to minimize the need for pod lifting and transportation tasks. Maximizing the number of items picked per pod visit stands as a linchpin in enhancing overall efficiency. This research endeavors to address the foundational principles underlying SKU allocation to pods, with a particular emphasis on optimizing performance metrics pile-on. Through the utilization of simulation methodologies, this study aims to demonstrate tangible improvements attainable through refined storage assignment strategies in RMFS environments.

Literature Review

As e-commerce grows, efficient warehouse management becomes vital. Robotic Mobile Fulfillment Systems (RMFS) utilize automatic guided vehicles (AGVs) to coordinate inventory movement. Effective in e-commerce scenarios, RMFS scales well and reduces costs (Boysen, De Koster and Weidinger 2019). Implementing RMFS involves strategic, tactical, and operational decisions. Tactical decisions, adjusted regularly, include SKU-to-pod assignments critical for operational efficiency (Merschformann et al. 2019). The Storage Assignment Problem (SAP) aims to optimize warehouse efficiency. Allocation decisions include SKU-to-pod, pod-to-zone, and dispersion of SKUs across pods (Mirzaei, Zaerpour, and De Koster 2022).

Common allocation strategies include random, dedicated, and class-based policies. (Zhang, Wang, and Pan 2019). Random assignment simplifies allocation but may require more effort for inventory tracking (Gu, Goetschalckx, and McGinnis 2007). Dedicated policies optimize picking travel distance but may need a larger warehouse (Muppani and Adil 2008; Gu, Goetschalckx, and McGinnis 2007). Class-based strategies, like ABC classification, assign SKUs based on popularity. Integrating Association rule with ABC classification improves SKU assignment to pods (Tsa et al. 2019). Cluster-based policies group correlated items to minimize costs and enhance throughput (Kim 1993). Cluster-based strategies can considerably boost the system’s throughput for order fulfillment (Mirzaei, Zaerpour, and De Koster 2022).

Problem Description

The storage assignment problem within Robotic Mobile Fulfillment Systems (RMFS) encompasses several critical allocation decisions, including the assignment of Stock Keeping Units (SKUs) to pods, the allocation of pods to zones, and the dispersion of SKUs across multiple pods (Mirzaei, 2021). Despite the importance of these decisions, our observations from company visits reveal a surprising reliance on random assignment policies. Moreover, existing proposed policies often lack precise procedures and fail to demonstrate persuasive real-world improvements in warehouse efficiency. Therefore, our research aims to address this gap by developing a provably better storage assignment policy for real-world RMFS warehouses.

Our proposed policy entails a comprehensive process to optimize storage assignment within Robotic Mobile Fulfillment Systems (RMFS). Initially, historical order data undergoes analysis to discern the demand distribution and order frequency of each Stock Keeping Unit (SKU). Subsequently, we conduct ABC classification based on SKU order frequency, with the number of classes dynamically adjusted to suit the data, ensuring an appropriate classification scheme. Following this, inventory policies are established for each SKU, and the quantity of each SKU to be allocated to pods is calculated, with different inventory policies applied based on SKU class. With SKU quantities determined, the next stepinvolves considering the ABC product mixture for each pod and product dispersionlevels concurrently. Determining the ABC mixture on each pod entails determiningthe required number of pods and the proportion of each class of SKU for each pod. Additionally, decisions are made regarding the separation of SKUs within pods. Finally, products are assigned to pods according to the pre-determined ABCproduct mixture and product dispersion levels, with priority given to products withhigher similarity when assigning products to the same pod. It's important to note that this research focuses solely on optimizing product-to-pod allocation and does not extend to the subsequent step of pod-to-zone allocation.

Our research is divided into two main parts. The first part focuses on virtual assignment, where we simplify the problem by disregarding product dimension constraints. We assume uniform product dimensions and slot capacities within pods, allowing us to focus on finding the optimal SKU combinations for each pod. We begin by determining the quantity of each SKU to be placed on the pods and then classify SKUs based on their order frequency. Additionally, we address the critical issue of SKU mixture within pods by exploring various ratios of SKU classes.

While this extreme scenario assumes uniform product dimensions, subsequent experiments will consider different product dimension scenarios.

In the second step, we integrate product dimension constraints, which are crucial for real-world applicability. Although pods and slots can be designed to accommodate specific SKUs, the rapid changes in product assortment within e-commerce contexts render such designs impractical. Therefore, we explore methods to maximize slot utilization and pod efficiency while accounting for product dimensions. To manage the complexity resulting from a large number of SKUs, we consider clustering to reduce them into manageable clusters. This phaseaims to evaluate how product dimensions influence optimal product mixtures and warehouse throughput. By incorporating product dimension constraints, our research aims to provide insights into the impact of physical product characteristics on warehouse operations within RMFS. Ultimately, this comprehensive approach will facilitate informed decision-making for warehouse management, bridging the gap between SKU allocation, product dimensions, and warehouse efficiency in RMFS environment.

We've already developed a simulation model for assessing storage assignment policies in RMFS. Initial results show promising improvements in warehouse efficiency. Next, we'll validate the model with real-world data, refine parameters, conduct sensitivity analyses, and compare against existing practices to provide actionable recommendations. This approach aims to enhance operational efficiency in e-commerce fulfillment.

Methodology

Simulation Layout

The simulation layout replicates an RMFS warehouse divided into three main areas: picking station, replenishment station, and storage area. The picking station facilitates item retrieval from pods, while the replenishment station handles pod replenishment. The storage area accommodates pod storage. The layout is depicted in Figure 1.

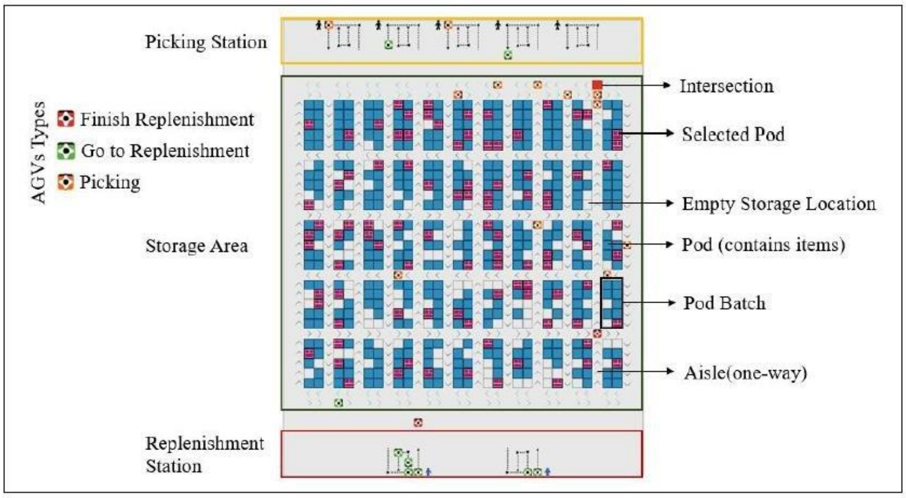

Figure 1. Layout of Simulation

AGVs are divided into 3 types to assign the pod based on the roles. In station areas, there are a worker and queueing line. Every time AGV comes to the station it lined up based on the queuing line. In the storage area, there are few elements such as:

(1) Intersection is a trigger for AGV to detect the route ahead (intersection).

(2) Selected Pod is a pod that contains some orders and waits to pick.

(3) Empty Storage Location is an available place to store the pod.

(4) The pod is a rack that contains many SKUs.

(5) Pod Batch is the size of the stored pod.

(6) An aisle is a place for AGV to move and design a one-way direction.

Simulation Platform

This study used 3 software to run the simulation: Netlogo, Python, and Microsoft Excel. Relation between each software can be seen in Figure 2.

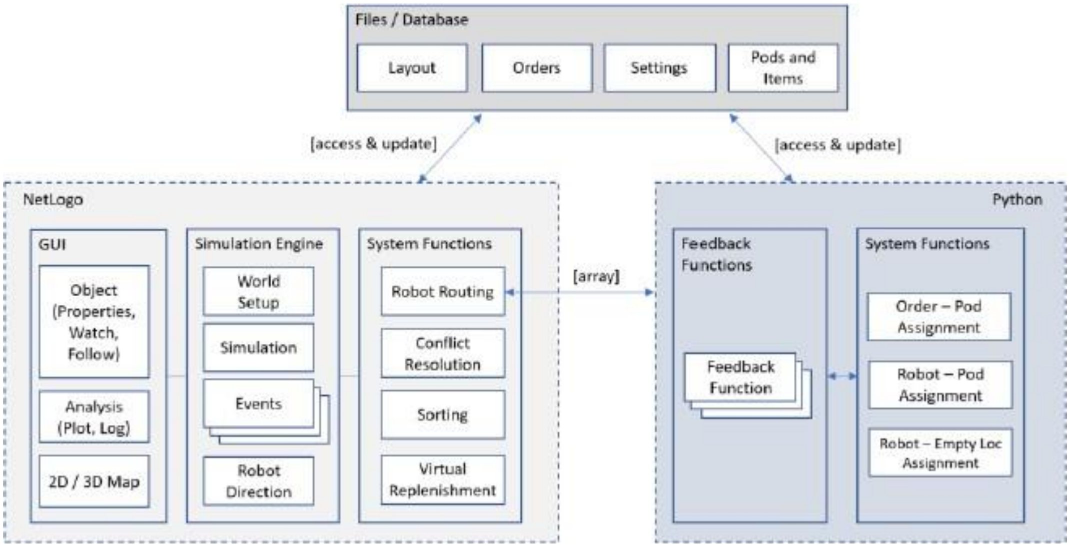

Figure 2. System Architecture

NetLogo serves as the agent-based modeling simulation platform, allowing for the creation of functions tailored to simulation requirements. While NetLogo provides a graphical user interface (GUI) for visualizing warehouse processes, it faces challenges in executing optimization problems. Python complements NetLogo by enabling optimization execution, while Microsoft Excel serves as the data storage for NetLogo and Python results..

Scenarios employed in Simulation

This research comprises two stages, aligning with the problem definition outlined earlier. In the initial stage, the focus is on virtual assignment, where a SKU-to-pod policy utilizing clustering is implemented to identify optimal product combinations that enhance warehouse throughput compared to a random SKU-to-pod policy. The second stage involves the integration of product dimensions into the analysis. Three simulation scenarios are employed:

(1) Random SKU-to-pod policy: Initially, a random SKU-to-pod policy is implemented, followed by assigning random product combinations to pods while considering product constraints.

(2) Class-Based SKU-to-Pod Policy with Association Rule: This scenario involves implementing a class-based SKU-to-pod policy integrated with association rules. First, SKUs are classified based on order frequency, and association rules are utilized to group products frequently bought together. The resulting product combinations are then assigned to pods while considering product constraints.

(3) Integrated Class-Based SKU-to-Pod Policy with Product Dimensions: This scenario involves simultaneously considering both the class-based assignment with association rules and product dimensions in the SKU-to-pod policy.

These scenarios aim to assess the effectiveness of the proposed SKU-to-pod policies in optimizing warehouse operations. The objective is to investigate whether increasing pod utilization to reduce the need for pods in the warehouse conflicts with assigning SKUs to pods to enhance throughput. The analysis aims to derive practical insights for companies based on the observed results.

Conclusion

In conclusion, this study has delved into the intricate dynamics of optimizing warehouse operations within Robotic Mobile Fulfillment Systems (RMFS) to meet the burgeoning demands of the e-commerce landscape. Through a comprehensive examination of the storage assignment problem and its various facets, we have elucidated the significance of effective SKU-to-pod allocation policies, particularly in the context of increasing efficiency while considering product dimensions. By initiating with virtual assignment, employing a class-based strategy integrated with association rules, and subsequently integrating product dimension constraints, this research aims to provide a holistic understanding of the interplay between SKU allocation, product characteristics, and warehouse efficiency. Insights gained from this study will not only enhance warehouse operations within RMFS but also contribute valuable insights to the broader domain of warehouse management in e-commerce settings.

Looking ahead, future endeavors will focus on refining the proposed methodologies, incorporating real-world data, and validating the findings through empirical studies. Through ongoing research and innovation, we aim to pave the way for more resilient and agile warehouse management practices in the era of digital commerce.

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